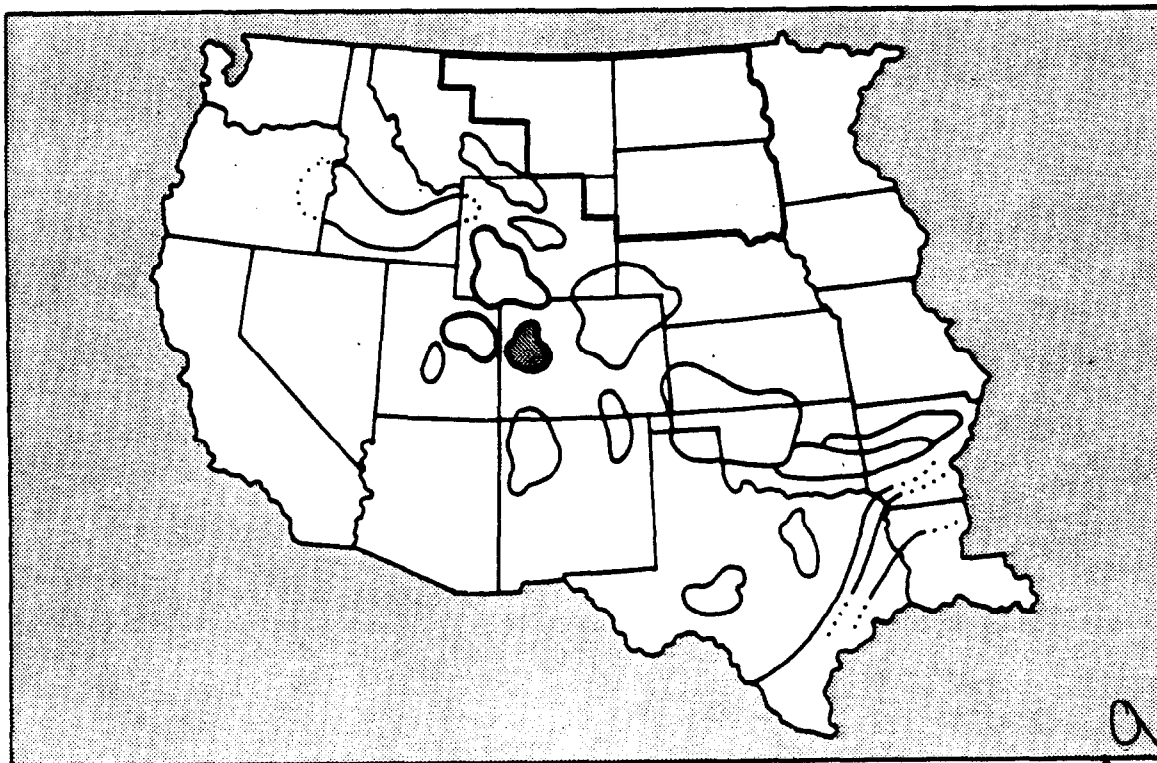


Western Gas Sands Project

STRATIGRAPHY OF THE PICEANCE BASIN



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Introduction

The Western Gas Sands Project Core Program was initiated by the United States Department of Energy to investigate various low permeability, gas bearing sandstones. Research to gain a better geological understanding of these sandstones and improve evaluation and stimulation techniques is being conducted. Tight gas sands are located in several mid-continent and western basins. This report deals with the Piceance Basin in northwestern Colorado.

This discussion is an attempt to provide a general overview of the Piceance Basin stratigraphy. It is not intended to represent original research or to be an exhaustive literature review. Rather, it is intended to be a useful reference of stratigraphic units and accompanying descriptions. A need for such a reference presently exists in the Western Gas Sands Project.

1. Location and Geologic Setting

As shown by Figure 1, the Piceance Basin is located in northwestern Colorado. It comprises 3,900 square miles of exposed Tertiary rocks in parts or all of Delta, Garfield, Mesa, Moffat, Pitkin and Rio Blanco Counties, Colorado. The basin is bound by an almost continuous outcrop of the Tertiary-Cretaceous contact and strong structural boundaries. The Uinta Mountains and Axial Basin Uplift form the northern border and the White River Uplift, which is represented by the spectacular Grand Hogback, forms the eastern and southeastern boundaries. The Uncompahgre Uplift forms the southwest boundary and the Douglas Creek Arch, the western boundary. The White River runs east-west across the northern portion of the Piceance Basin and the Colorado River runs east-west across the southern portion.

The Basin is a large northwest trending structural downwarp strongly asymmetric with a gentle dip on the southwest flank and a much stronger dip on the northeast flank. The basin is modified by smaller structural features including anticlines, synclines, fracture and joint systems and high angle normal faults with small displacements.

Sedimentary rocks form a continuous maximum sedimentary sequence of 27,000 ft (Figure 2). This represents the maximum structural relief from Precambrian basement complex in the lowest portions of the central Piceance Basin to the highest parts on the White River and Uncompahgre Uplifts.

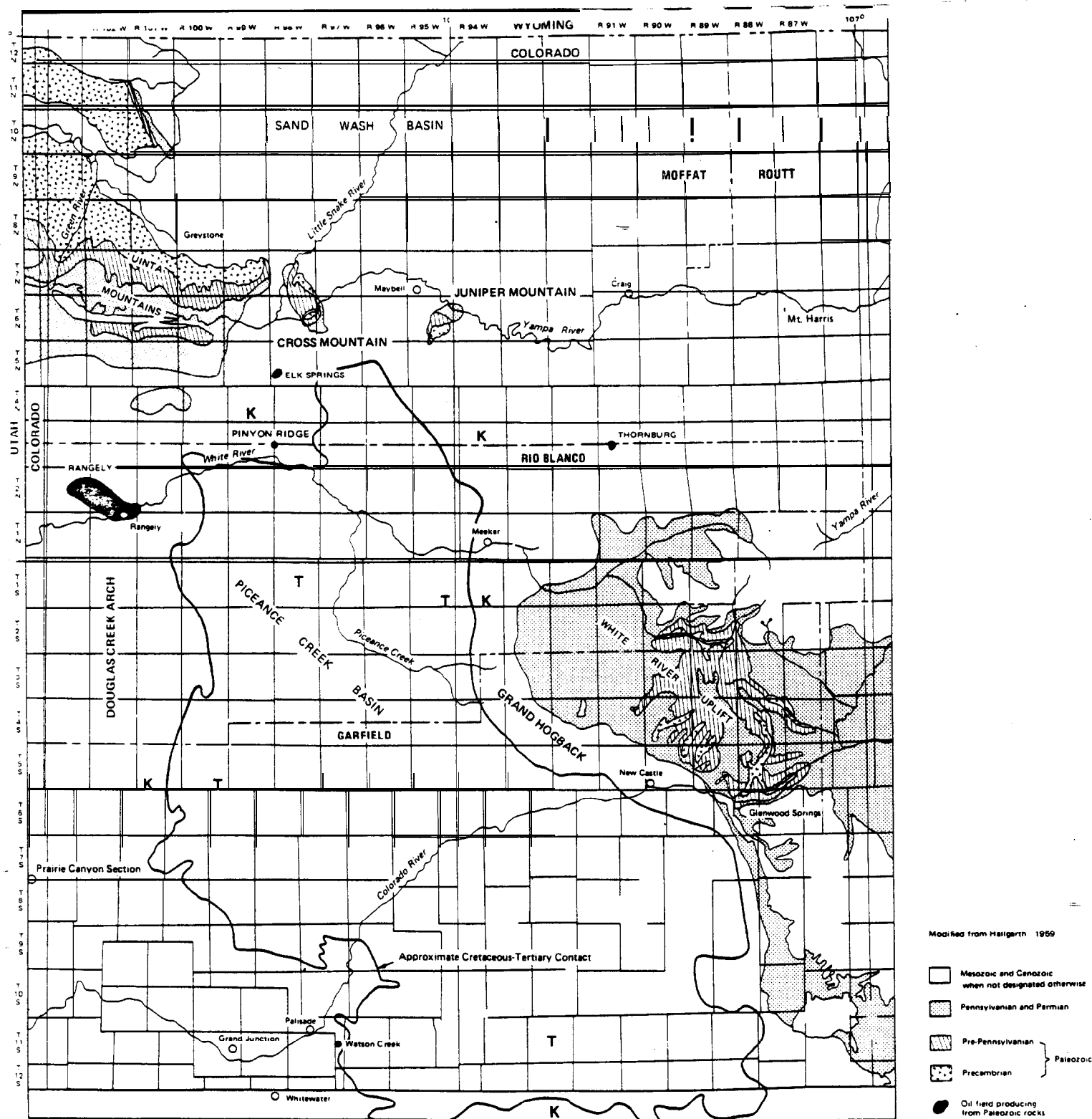


Figure 1 Location of the Piceance Basin

System	Series	Stratigraphic Unit		Related Units
Tertiary	Eocene	* Green River Formation	Uinta Formation	Anvil Points Member
			Parachute Creek Member	
			Garden Gulch Member	
			Douglas Creek Member	
	Paleocene	* Wasatch Formation		
			Fort Union Formation	
Cretaceous	Upper Cretaceous	* Mesaverde Group	Ohio Creek Conglomerate ? — ?	
			Lance Formation	
			Fox Hills Sandstone	
			Lewis Shale	
			Lion Canyon Sandstone	
			Williams Fork Formation	Hunter Canyon Formation
			Hes Formation	Mount Garfield Formation
			Sego Sandstone	
			Castlegate Sandstone	
	Lower Cretaceous	* Mancos Shale	"Main Body" of Mancos Shale	
			Niobrara Equivalent	
			Frontier Member	
			Mowry Shale Member	
	Lower Cretaceous	* Dakota Sandstone		
		* Cedar Mountain Formation		Burro Canyon Formation

*
Oil and/or Gas Productive

Figure 2 Generalized Section of the Piceance Basin

Jurassic		Upper Jurassic	*	Morrison Formation		
				Curtis Formation	Summerville Formation	
		Middle Jurassic	*	Entrada Sandstone		
				Carmel Formation		
Triassic		Lower Jurassic		Navajo Sandstone	Nugget Sandstone Glen Canyon sandstone	
		Late Triassic		Chinle Formation		
			Early Triassic	*		Shinarump Conglomerate
				Moenkopi Formation		
Permian		Leonardian and Guadalupian		Park City, Phosphoria, Woodside Formations		
		Wolfcampian	*	Weber Sandstone		
Carboniferous	Pennsylvanian	Missourian and Virgilian		Maroon Formation		
		Des Moinesian		Paradox Formation		Minturn Formation
		Morrowan and Atokan		Belden Formation		
			Molas Formation			
	Mississippian	Osagean		Leadville Limestone	Madison and Desert Limestones	
Unconformity						
Devonian		Upper Devonian	Chaffee Group	Dyer Formation		
				Paria Formation		
Ordovician		Canadian Series	Manitou Formation	Tie Gulch Dolomite Member		
				Dead Horse Conglomerate Member		
Cambrian		Upper Cambrian	Dotsero Formation	Cinetop Algal Member	Lodore Formation	
				Glenwood Canyon Member		
			Sawatch Quartzite			
Precambrian			Uinta Mountain Group			
			Older Precambrian Rocks			

Figure 2 Continued

2. Stratigraphy

2.1 PRECAMBRIAN ROCKS

Exposures of Precambrian rocks are restricted to uplifts in northwestern Colorado. Exposures are very limited in areal extent and primarily occur in deep canyons of the Colorado River and South Fork of the White River, although farther east in central Colorado extensive Precambrian outcrops occur. Precambrian rocks buried beneath sedimentary rocks exist above sea level in these uplifts and probably extend uninterrupted into the Piceance Basin at elevations below sea level.

Curtis (1962) describes two major divisions of Precambrian rocks. Older Precambrian rocks consist of a complex series of crystalline metamorphics intruded by granitic igneous rocks with preserved sedimentary and volcanic features. This older Precambrian complex is 1,456 to 1,750 million years old. (Hedge, 1972).

Younger Precambrian rocks, belonging to the Uinta Mountain Group, are composed of reddish-brown, poorly sorted quartzitic and conglomeratic sandstones. These rocks are at least 20,600 ft thick in the Uinta Mountains, but probably do not extend more than a few miles beyond the present Uinta Mountain axis. Hedge (1972) calculated their age to be greater than 600 million years and less than 1,700 million years.

2.2 CAMBRIAN SYSTEM

UPPER CAMBRIAN SERIES

Sawatch Quartzite

The Sawatch Quartzite and Dotsero Formation form the Upper Cambrian section in the White River Uplift. Sawatch Quartzite unconformably overlies the Precambrian complex. Bass and Northrop (1963, p. J4-J7) described the Sawatch Quartzite in the Glenwood Springs area. Here, the Sawatch Quartzite is about 500 ft thick with beds commonly ranging from 2 to 5 ft in thickness. A few units of thin-bedded dolomite exist. The formation is interbedded with beds of greenish-gray shale that is a fraction of an inch to several inches in thickness. Regular bedding is one of its chief characteristics.

Dolomite, 75 ft or more in thickness, composed of dark-brown thin-bedded dolomite and sandy dolomite with considerable glauconite is present in the upper part of the formation. The glauconite gives the formation a purplish-black color upon weathering. Beds of quartzite are more abundant above this dolomite unit. The only fossils found by Bass and Northrop (1963) were a few chitino-phosphatic brachiopods in this dolomite unit.

Dotsero Formation

The Dotsero Formation is restricted to 400 square miles on the White River Plateau. Bass and Northrop (1963, p. J7-J13) described the Dotsero in the Glenwood Springs area as a 96- to 106-ft thick section directly above the Sawatch Quartzite; the formation includes the Glenwood Canyon Member and the Clinetop Algal Member which comprises the top few feet of section.

The basal contact is usually distinguished by the ledge and cliff forming Sawatch Quartzite. However, the local basal beds of the Dotsero Formation are sandy. The Upper Cambrian limit is distinguished by the faunal assemblage in the Clinetop Algal Limestone Member.

The lower half of the Glenwood Canyon Member is composed of thin beds of light-gray to tannish-gray dolomite and a few thin beds of flat-pebble dolomite conglomerate interbedded with thin beds of light-greenish-gray very dolomite shale. The upper half of this member consists of thin beds of flat pebble limestone conglomerate and interbedded light-greenish-gray very limey shale. Fossils found in the member include sponges, graptolites, trilobites, and brachiopods. They are described in detail by A. R. Palmer (in Bass and Northrop, 1953, p. 908-911).

The Clinetop Algal Limestone Member consists of coarse flat-pebble limestone conglomerate, and the upper half consists of crystalline to dense algal limestone with a crinkly to wavy structure and some conglomerate. Fossils include algae, sponges, pelmatozoan columnals, brachiopods and trilobites. J. Harlan Johnson (in Bass and Northrop, 1953, p. 900-911) considers the algae to be an undescribed species of *Collenia*.

In the absence of the Clinetop Algal Limestone Member, the Manitou (see below) and Dotsero cannot be subdivided and are called Dotsero.

Hallgarth (1959) considers subsurface correlations of Cambrian rocks exposed in the White River Uplift as uncertain northwest beyond Juniper Mountain. He calls the entire sequence the Lodore Formation due to the lithologic resemblance to the Lodore of the Uinta Mountains. Well logs indicate the lower part is composed predominately of sandstone and the upper part of silty and shaly sandstone, which probably correlates with the Sawatch and Dotsero respectively. With this in mind, a gradational lithologic change must occur west of the White River Uplift across the Piceance Basin along a north-south axis.

2.3 ORDOVICIAN SYSTEM

CANADIAN SERIES

Manitou Formation

The Manitou Formation, as designated by Bass and Northrop (1953, p. 905), includes slightly more than half of the Dotsero Dolomite of Basset (1939, p. 1855-1858). Bass and Northrop (1953) restricted the name "Dotsero" to Cambrian beds and applied Manitou to the Ordovician sequence. The Manitou Formation ranges from zero to over 200 ft in thickness and consists primarily of dolomite which is gray to tan, dense, partly crystalline, cherty and, in places, sandy. Locally, the Manitou grades to dense red dolomite or shaly dolomite (Foster, 1972, p. 76). The Manitou is divided into the Dead Horse Conglomerate Member and Tie Gulch Dolomite Member.

Bass and Northrop (1963, p. J14-J17) described the Dead Horse Conglomerate Member and Tie Gulch Dolomite Member in the Glenwood Springs area. Here the Dead Horse Conglomerate Member forms the lower portion of the Manitow Formation. It consists largely of thin beds of gray flat-pebble limestone conglomerate which are similar in description to the Glenwood Canyon Member of the Dotsero Formation. Conglomerate beds are 3 to 12 in. thick and shale beds are usually thinner. Fossils include trilobites, brachiopods, gastropods, a cephalopod, conodonts, sponge spicules, pelmatozoans and graptolite.

The Tie Gulch Dolomite Member consists of a regular and thin-bedded, medium-brown dolomite which commonly forms a cliff.

Most Tie Gulch dolomite is fine to medium grained. Many beds are slightly siliceous and a few are quite sandy. Thin stringers of light-yellow chert are present in weathered outcrop. No fossils were found by Bass and Northrop (1953, p. J17).

2.4 SILURIAN SYSTEM

Hintze (1970), in studying the Silurian of Utah, considered the uniformity of the faunal composition, mostly corals and brachiopods, indicative of a widespread warm and shallow-water marine depositional environment far from any significant source of clastics.

Gibbs (1972) considers the Silurian sea one of the most widespread of the Paleozoic epeiric seas. He suggests that only remnants of Silurian age rocks exist due to the extensive post-Silurian –pre-Middle Devonian erosional interval. Deposits of Silurian age are therefore not known in the Piceance Basin and adjacent areas.

2.5 DEVONIAN SYSTEM

UPPER DEVONIAN SERIES

Campbell (1970) changed the terminology used by Bass and Northrop (1963). Campbell upgraded the Chaffee "Formation" to a group status and the Parting and Dyer "Members" to a formation status. Original definitions of these units were not altered. Campbell (1969) did designate discontinuous but recognizable units for the Parting Formation and new members for the Dyer Formation. The following is a review of Campbell's descriptions.

Parting Formation

Campbell (1970) divided the Parting Formation into three recognizable lithologic units: A, B and C. Total thickness for all three units according to Bass and Northrop (1963) is 63 to 95 ft. Unit A is a medium to coarse grained quartzose sandstone cemented by silica with local thin arenaceous shale. Sedimentary structures include a few burrows, ripple marks and abundant crossbedding. Unit A is unconformably underlain by the Manitou Formation and conformably overlain by Unit B.

Unit B of the Parting Formation is uniform in lithology, thickness and distribution. It consists of a basal gray shale; a thin, dense, dark-gray, irregularly-bedded dolomite; an upper gray shale; and a thin bed at the top that consists of a mixed sandy dolomite, dolomitic sandstone or interbedded dolomite and sandstone.

Unit C is the least consistent in thickness and lithology of the units found in the Parting Formation. Lithology ranges from shale to dolomite to quartzose sandstone cemented with silica. The beds are discontinuous. The shales are gray to green and often are both micaceous and arenaceous. Locally, they may be dolomitic. They are commonly interbedded with thin, finely crystalline, dense dolomite beds and greenish to gray, medium- to finegrained quartzose sandstone or siltstone beds. The contacts of Unit C with the overlying Dyer Formation and underlying Unit B are conformable and often gradational.

Dyer Formation

Campbell (1970) recognizes two members in the Dyer Formation; the lower dolomitic limestone is the Broken Rib Member, the upper dolomite is the Coffee Pot Member. Overall thickness is approximately 162 ft.

The Broken Rib Member is a gray to dark-gray dolomitic limestone with some beds of almost pure dolomite. It is basically a micrite carbonate with fine to coarse fossil fragments and complete fossils. Brachiopods are the most abundant complete fossils and pelmatozoan columnals and plates are the most abundant fragments. Contacts of the Broken Rib Member with the underlying Parting Formation and the overlying Coffee Pot Member appear conformable.

The Coffee Pot Member is a finely crystalline, dense gray to dark-gray dolomite which locally is calcareous. The beds are mainly thin, have a typical angular and blocky weathering habit and have sharp regular or irregular contacts.

What appear to be stromatolites are prominent in outcrop. The Coffee Pot Member is disconformable with the overlying Leadville Limestone.

Hallgath (1959) indicates a probable subsurface continuity of the Chaffee Group west to the Rangely Field. However, thinning occurs toward the Juniper and Cross Mountains in the north where rocks of Devonian age are not recognized.

2.6 MISSISSIPPIAN SYSTEM

OSAGEAN SERIES

Leadville Limestone

Rocks of the Lower Mississippian age are assigned to the Leadville Limestone in the Glenwood Springs area. This is based on physical correlation with the Leadville Limestone of the type area, about 50 miles southeast of Glenwood Springs by Bass and Northrop (1955, p. 9).

The basal 30 ft of the Leadville consists of gray and buff, finely granular and finely crystalline, cherty dolomite and limestone. Thin lenses of sandstone and scattered grains of sand are present. Bedding and irregularities suggestive of disconformities are present at the base and within the unit (Hallgarth, 1959).

The upper half of the Leadville consists of massive, cream, gray, buff, brown, and brownish-gray, finely to coarsely crystalline and partly granular, oolitic limestone. Between this oolitic portion and the basal portion are interbedded massive limestone and dolomite beds containing dark-gray chert in the lower part (Hallgarth, 1959).

Fossils are not common in the Leadville Limestone. Johnson (1945) did describe a number of species present — algae, foraminifera, brachiopods, gastropods and others were identified.

Correlative Osage age rocks in northeastern Utah are referred to as the Madison and Deseret Limestones. Tweto (1976) on his preliminary geologic map of Colorado extends the term Madison Limestone to outcrops at Juniper Mountain. This seems logical, but where the boundary should be drawn between the Madison and Deseret Limestones and Leadville Limestone in the subsurface is unclear.

2.7 PENNSYLVANIAN SYSTEM

INTRODUCTION

The Pennsylvanian rock sequence in the White River Uplift consists, in ascending order, of (1) the Molas Formation — a thin, dark-purplish-red argillaceous unit; (2) the Belden Formation — a series of dark-gray beds of shale and limestone with beds of arkosic grit in the upper part; (3) the Paradox Formation — a unit with thick beds of gypsum and block shale (Hallgarth, 1959); and (4) the Maroon Formation of Pennsylvanian and Permian age (Bass and Northrop, 1963, p. 530).

MORROWAN AND ATOKAN SERIES

Molas Formation

The type locality for the Molas Formation is in southwestern Colorado and was originally described by Girty (1903, p. 247). A portion of the Lower Molas Formation is considered Upper Mississippian in age. The exact age boundary is difficult to determine (Henbest, 1958, p. 37). Hallgarth (1959) described the formation as exposed along Deep Creek on the south flank of the White River Uplift. Here the formation is a thin maroon-colored sequence of clay, shaly sandstone and chert-pebble conglomerate resting on the karst surface of the Leadville Limestone. Bass and Northrop (1959) indicate a thickness of 1 to 25 ft.

Hallgarth (1959) found a similar unit in the boreholes that he was able to trace west to the Douglas Creek Arch. However, he did not recognize the formation in the Cross and Juniper Mountains to the northwest.

Belden Formation

Bass and Northrop (1963, p. J34) redefined the Belden Formation as originally described by Brill (1944, p. 624). They extended its contact with the underlying Molas Formation upward to the base of the lowest prominent gypsum bed of the overlying Paradox Formation. Bass and Northrop (1963, p. J34-J41) defined the Belden Formation at Deep Creek. Here the formation is approximately 1,000 ft thick. The lower 675 ft consists of dark-gray to almost black shale and limey shale, interbedded thin-bedded gray to almost black shale and limey shale and a few very thin beds of black coaly shale. In nearby localities a bed of coal and beds of gypsum are present. The upper 175 ft of this sequence contains mostly shale and a few thin beds of finegrained very micaceous greenish-tan sandstone.

The 140 ft of formation lying above this 675 ft sequence consists almost exclusively of fissile dark-gray shale and thin-bedded, micaceous, greenish-tan sandstone. Above this are thick beds of coarse arkosic gritstone interbedded with arkosic conglomerate and fissile black shale (Bass and Northrop, 1963, p. J35).

Fossils are locally abundant and diversified in the Belden Formation and overlying Paradox Formation. A description of these fossils is included by Bass and Northrop (1963).

Hallgarth (1959) showed that in the subsurface between the White River Uplift and Juniper Mountain the rocks referred to as the Belden Formation are lithologically similar to the Morgan Formation which crops out farther northwest. The wells utilized indicate a unit that is dark-gray and brownish-gray, fossiliferous, locally cherty with oolitic limestone interbedded with dark-gray and greenish-gray shale, and green, gray, and brown sandstone, of which some beds are oolitic and others are arkosic. Hallgarth (1959) placed a questionable Belden and Morgan boundary between a well northwest of Thornburg and the Juniper Mountain.

DES MOINESIAN SERIES

Paradox Formation

Bass and Northrop (1963, p. J42-J46) described the Paradox Formation at Blowout Hill on the east side of the Colorado River in the White River Uplift. Here the formation is 553 ft thick. It consists of thick beds of gypsum, interbedded black and gray shale, reddish gypsiferous siltstone and shale, and brown to yellow shaley sandstone. These same deposits are also referred to as the Minturn Formation which contains the Jacque Mountain Limestone and Eagle Evaporite Members.

Hallgarth (1959) identified the Paradox Formation in wells southeast of Thornburg. Northwest of Thornburg he found that the formation interfingers with parts of the Morgan Formation. Hallgarth (1959) terminated the Paradox Formation just west of the Juniper Mountain.

2.8 PENNSYLVANIAN AND PERMIAN SYSTEMS

The Pennsylvanian and Permian rocks in the White River Uplift consist of a thick sequence of red beds of Pennsylvanian and Permian age known as the Maroon Formation. It contains an apparent Weber Sandstone tongue and a thin dolomite and limestone unit in the upper part (Hallgarth, 1959).

MISSOURIAN, VIRGILIAN AND WOLFCAMPIAN SERIES

Maroon Formation

Bass and Northrop (1963, p. J46-J47) described the Maroon Formation as that sequence of red beds between the gypsumbearing Paradox Formation below and the overlying Chinle Formation southeast of Cross Mountain. At Glenwood Springs, it is about 3,350 ft thick. The formation consists predominately of red even-bedded shale, siltstone, sandstone and conglomerate, and a few thin beds of dark-gray dense limestone. Many beds are arkosic and most are micaceous. Beds of conglomerate alternate with beds of silty shale. The upper 50 to 100 ft is considered Wolfcampian (Permian) in age (Bass and Northrop, 1963, p. J47).

Included in this 50 to 100 ft in the Upper Maroon Formation is a thin unit of fossiliferous limestone 18 in. to 6 ft thick. It is referred to as the South Park Canyon Creek Member of the Maroon Formation (Bass and Northrop, 1963, p. J48).

On the Douglas Creek Arch, Hallgarth (1959) described the Maroon Formation from well samples as a red, poorly-sorted, angular-grained, micaceous, arkosic sandstone and conglomerate with thin interbeds of reddish-brown and maroon shale and reddish-gray limestone. Near the Rangely Oil Field the Maroon Formation grades into the Weber Sandstone and part of the Morgan Formation.

WOLFCAMPIAN SERIES

Weber Sandstone

The Weber Sandstone is Pennsylvanian and Permian in age (Bass and Northrop, 1963, p. J47). It is 800 to 1,000 ft thick in outcrops at Cross Mountain (Hallgarth, 1959). The Weber Sandstone here is a light-colored, crossbedded sandstone forming massive cliffs (Thomas, McCann, and Roman, 1945). In the Rangely Field and on the Douglas Creek Arch the Weber interfingers with arkosic red beds (Hallgarth, 1959).

Southeastward from the Rangely Field the Weber thins markedly but persists as a tongue of light-gray sandstone in the upper part of the Maroon Formation on the outcrop along the southwest flank of the White River Uplift. The lower part of this tongue consists of gray and greenish-gray, irregularly bedded, coarse-grained micaceous, arkosic sandstone, and greenish-gray, coarsely sandy shale containing large flakes of mica. The upper part consists of light- and dark-gray-banded, medium-bedded, very fine to finegrained, in part crossbedded sandstone containing some oil residue (Hallgarth, 1959).

2.9 PERMIAN SYSTEM

ROCKS OF PERMIAN AND PERMIAN (?) AGE UNDIFFERENTIATED

There is a sequence of limestone, cherty limestone, and gray and yellow calcareous siltstone, sandstone and shale of Permian and Permian (?) age overlying the Weber Sandstone in northwestern Colorado (Hallgarth, 1959). Rascoe and Baars (1972) indicated that these units are a combined sequence of Park City, Phosphoria and Woodside Formations which interfinger with the upper Maroon Formation southeast of the Uinta Uplift.

2.10 TRIASSIC SYSTEM

EARLY TRIASSIC SERIES

Moenkopi Formation and Shinarump Conglomerate

At Cross Mountain, northwest of the White River Uplift, the Moenkopi represents the Lower Triassic. It is 503 ft thick and consists of a basal unit of gray shale which grades upward into tan, very fine grained sandstones and yellow shales. Unconformably overlying the Moenkopi Formation is the dark reddish-black Shinarump Conglomerate. It is 13 ft thick, and grades upward into the Chinle Formation. Both the Moenkopi Formation and Shinarump Conglomerate terminate southeast of Cross Mountain.

LATE TRIASSIC SERIES

Chinle Formation

In the White River Uplift, a rock sequence about 325 ft thick of orange-red shale, siltstone and limestone-pebble conglomerate represents the Chinle Formation of Upper Triassic age (Bass and Northrop, 1963, p. J54). Its lower contact with the Maroon Formation is drawn at the contact of a dull maroon shale with an overlying orange-red silty to sandy shale. The upper boundary is unconformable with the overlying Navajo Sandstone.

MacLachlon (1973) indicates that the Chinle and Moenkopi Formations are continuous in the subsurface across the Piceance Basin into Utah.

2.11 TRIASSIC AND JURASSIC SYSTEMS

LATE TRIASSIC AND LOWER JURASSIC SERIES

Navajo Sandstone

The geographic boundaries between the time equivalent Nugget, Navajo and Glen Canyon Sandstones are unclear. Navajo Sandstone is used in this report to designate eolian deposits of Late Triassic — Lower Jurassic age.

Exposures of Navajo Sandstone are present at Cross Mountain. A measured section by Abrassart (1951) indicates a thickness of about 804 ft. It pinches out to the south in the central Piceance Basin and to the southeast at the White River Uplift.

A description by Hansen (1965) to the northwest of Cross Mountain indicates the Navajo Sandstone is a very homogeneous formation. It consists of fine- to medium-grained sandstone composed of subangular to rounded frosted quartz grains. The sandstone is pink, tan or brown on exposed cliff faces due to desert varnish. Fresh surfaces are cream colored to almost white.

The Navajo Sandstone forms prominent cliffs with striking large scale crossbedding. Its hardness on induration is related to type and degree of cementation which may be either calcareous or siliceous. Crossbedding has been attributed to eolian deposition.

2.12 JURASSIC SYSTEM

LOWER AND UPPER JURASSIC SERIES

Entrada Sandstone

Bass and Northrop (1963, p. J54) described the Entrada Sandstone in the White River Uplift. Here it is 100 ft thick, and extends in subsurface to all but the southern portion of the Piceance Basin. The Entrada Sandstone consists mostly of very fine to fine well sorted subangular grains of clear quartz cemented with a slightly calcareous cement. The Entrada Sandstone forms a prominent light-gray ledge at most exposures.

With the absence of the Cannel Formation in most or all of the Piceance Basin (literature does not clarify this point), the Navajo and Entrada Sandstones are referred to as Entrada Sandstone.

UPPER JURASSIC SERIES

Curtis Formation

Wright and Dickey (1979) described the Curtis Formation in a section measured on the northeast flank of the White River Uplift. Here it is 111 ft thick and consists of interbedded sandstones, limestones and claystones. Sandstones contain abundant glauconite which gives it a green cast in outcrop. Fossils are abundant throughout the formation.

The Curtis Formation is continuous in subsurface through the Piceance Basin to the White River Uplift where it thins and terminates. In the southwestern part it grades into the Summerville Formation,

Morrison Formation

Bass and Northrop (1963) described the Morrison Formation in the White River Uplift. Here the formation is 480 to 600 ft thick. It consists of palegreen shale interbedded with maroon shale, light-gray sandstone, and a few beds of dark-gray limestone. The sandstones consist largely of fine quartz grains and contain a greater proportion of red, green and brown grains than the Entrada Sandstone. Thin beds of limestone are present at several horizons in the formation.

The Morrison Formation is continuous in subsurface through the Piceance Basin. It is a very widely distributed formation in the Rocky Mountain area. The Morrison is noted for the abundance of dinosaur remains. More recently it has become known for extensive uranium deposits being mined on the Colorado Plateau.

2.13 CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

Aptian Stage

Cedar Mountain Formation

Young (1959, p. 17-18) described the Cedar Mountain Formation near Grand Junction, Colorado. Here the formation is approximately 115 ft thick. It consists of a basal conglomeratic sandstone unit and an overlying variegated mudstone unit.

The basal sandstone is a massive cliff-forming sandstone with an undulatory base and a sharply defined upper surface. It is composed primarily of angular to subrounded quartz grains cemented with clay or calcium carbonate.

Overlying the sandstone is a unit of light-gray to green, silty, calcareous mudstone. Lenses of conglomerate, sandstone and siltstone are present in the mudstone. Some of these have been converted partially or entirely to gray or green quartzite.

The formation appears to be continuous through the Piceance Basin to the White River Uplift (Young, 1959, p. 17-18).

Stokes (1952) selected the Colorado River as an arbitrary boundary between the Cedar Mountain Formation to the west and the Burro Canyon Formation to the east. Young (1959) found the two formations to be a continuous unit and discarded the term "Burro Canyon." This is mentioned to clarify references in the literature to the "Burro Canyon Formation."

Albian Stage

Dakota Sandstone

The highly carbonaceous sequence of rocks above the Cedar Mountain Formation have been referred to variously as the "Dakota Sandstone", "Dakota" and "Dakota Formation." In order to eliminate this confusing terminology, Young (1959) introduced the name Naturita Formation to these deposits. He referred to the Cedar Mountain Formation and the Naturita Formation as the Dakota Group. Fisher, Erdmann, Reeside (1980, p. 8) refer to the deposits as Dakota Sandstone which conforms to the usage found in most literature. The author feels that the term "Dakota Group" is unnecessary; the name Dakota Sandstone is adequate for these deposits.

Young's (1959, p. 21) description of the Naturita Formation is applicable, although here it is referred to as the Dakota Sandstone. A thin, 5- to 15-ft, conglomeratic sandstone composed of angular to subrounded quartz grains, pebbles of milky quartz, gray quartzite and gray to black tripolitic chert forms the basal unit in most of the area. The main cementing agents are clay and silica. Its unusual color is light gray on fresh surfaces and buff on weathered surfaces. It disconformably overlies the Cedar Mountain Formation.

In much of the area a similar sandstone occurs above this lower unit, separated from it by as much as 45 ft of carbonaceous deposits.

The upper unit, as described by Young (1959, p. 21), consists of gray to black silty carbonaceous mudstone with lenses of conglomerate, sandstone, siltstone, carbonaceous shale and coal. This unit is disconformably overlain by the Mancos Shale.

LOWER AND UPPER CRETACEOUS SERIES

Mancos Shale

Kucera (1959) did a dissertation on the geology of the Yampa district from the Park Range to the White River Plateau, northwest Colorado. Part of his research was presented in the 1959 RMAG Symposium Guidebook. This paper described the main lithologic characteristics of Cretaceous formations east of the Piceance Basin. The following descriptions of the Mowry, Frontier, Mancos and Mesaverde Group are modified versions of those presented by Kucera.

Kucera referred to the Mowry, Frontier and Niobrara as "formations." More recent literature, specifically Tweto's (1976) "Preliminary Geologic Map of Colorado," refer to the Mowry and Frontier as "members" of the Mancos Shale and to the Niobrara as the "Niobrara Equivalent" within the Mancos Shale.

Therefore, the nomenclature presented by Kucera has been altered here to match current designations. The portion described by Kucera as Mancos Shale is referred to here as the "Main Body" of the Mancos Shale.

Albian Stage

Mowry Shale Member

The Mowry Shale ranges from 125 to 200 ft thick in the Yampa district. It grades downward into alternating thin-bedded light-gray sandstones and shales at the top of the Dakota Sandstone, and is overlain conformably by dark-gray shales and siltstones of the Frontier Member. Lateral continuity is displayed by the Mowry throughout northwestern Colorado.

The Mowry shales are commonly dark gray to black and locally brownish gray to olive gray, silty and siliceous. They display carbonaceous laminations, fish bones and scales along bedding surfaces. The upper part contains yellowish-gray to light-gray calcareous siltstones. Bentonite beds and stringers are common throughout the Mowry.

Turonian Stage

Frontier Member

In the Yampa District the Frontier Member ranges from 274 to 375 ft thick. It consists of a lower shale unit and an upper sandstone unit. The Frontier Member is underlain conformably by dark-gray, siliceous Mowry Shale and overlain in gradational contact by light-gray limestone and shale of the Niobrara Equivalent. Bass and Northrop (1963, p. J56) and McGookey (1972) indicate that in some areas of northwestern Colorado, the Frontier Member is underlain by Mancos Shale which in turn overlies the Mowry Shale. It is laterally continuous in northwestern Colorado.

The shale unit of the Frontier consists of medium- to dark-gray, silty, slightly calcareous shale, some medium-gray, siltstone horizons and interbedded light-gray bentonite beds up to 4 inches thick.

The sandstone unit consists of brownish-gray to yellowish-gray, very fine- to finegrained, carbonaceous sandstone in the lower part, and light-olivegray to brownish-gray siltstones and interbedded medium dark-gray shale in the upper part.

Upper Turonian and Santonian (?) Stages

Niobrara Equivalent

The Niobrara Equivalent is 600 to 900 ft thick in the Yampa district. It is a succession of gray siliceous shale, limestone, siltstone, bentonite and gypsum which is underlain by the sandstone unit of the Frontier Member and conformably overlain by the Mancos Shale. The upper boundary is gradational which makes identifying a definite Niobrara-Mancos "Main Body" contact impossible.

The Niobrara Equivalent loses its speckled character westward across northwestern Colorado and blends into the Mancos Shale.

Turonian and Campanian Stages

"Main Body" of the Mancos Shale

The "Main Body" of the Mancos Shale is up to 5,900 ft thick in the Yampa district. It is a thick succession of shale, sandy shale and thin-bedded sandstone overlying the Niobrara Equivalent and underlying the Mesaverde Group. Sandy shales and sandstones grade upward and interfinger with the Two Creek Sandstone, a basal member of the Iles Formation. It is laterally continuous through northwestern Colorado.

The lower part of the "Main Body," as much as 2,775 ft thick, consists of a variable sequence of shale, sandstone and minor amounts of limestone and bentonite. This is overlain by 2,100 ft of brownish-gray to olive-gray, silty shale that contain limonitic concretions up to 1 ft thick, lenticular limestone beds up to 4 ft thick, bentonite layers in the middle part, and light-gray to olivegray, very fine to finegrained, calcareous glauconitic sandstones in the upper part.

The upper part of the "Main Body" of Mancos Shale is characterized by silty to sandy shales and thin-bedded, ledge-forming sandstone, 735 to 980 ft thick. At the base is a sandstone sequence that is 240 to 260 ft thick and consists of three prominent yellowish-gray to light-gray, fine-grained, crossbedded sandstone units with intervening slopeforming sandy shale and thin sandstone zones.

Overlying this sandstone sequence is a series of thin-bedded ledgeforming sandstones and interbedded sandy shales and siltstones. The sandy zones increase toward the top of the "Main Body" forming subordinate benches, escarpments and hogbacks in the hillslopes underlying sandstone cliffs in the lower part of the Hles Formation.

On the Douglas Creek Arch the Mancos "B" is an important-gasbearing zone in the upper 1,700 ft of the "Main Body." Kopper (1962) described the Mancos "B" as finely interbedded sands and shales. The sands are fine to medium grained, poorly-sorted with a clayey matrix. The relationship between the Mancos "B" and the "Main Body" sands described by Kucera has not been established.

Perhaps the Meeker in the Sand Wash Basin, a portion of the sands described by Kucera in the Yampa area, the Emery in Central Utah and the Mancos "B" are related to a common depositional environment

UPPER CRETACEOUS SERIES

Campanian and Maestrichtian Stages

Mesaverde Group

The Mesaverde Group is subdivided in the Book Cliffs area west of the Colorado-Utah bwndry into seven units, termed the Neslen, Farrer and Tuscher Formations, Sego Sandstone, Buck Tongue of Mancos Shale, Castlegate Sandstone and Blackhawk Formation. East of the Colorado-Utah bwndry five units are recognized termed the Mount Garfield and Hunter Canyon Formations, Sego Sandstone, Buck Tongue of Mancos Shale and Castlegate Sandstone (Fisher, Erdman and Reeside, 1960, p. 11). East of Palisade, Colorado the comparable interval is referred to as the Mesaverde Formation (Gill and Hail, 1975). In the northern Piceance Basin and along the Grand Hogback south to the Colorado River, the Mesaverde Group is subdivided into two units, termed the Williams Fork and Hles Formations (Tweto, 1974).

Rollins Sandstone	Buck Tongue of Mancos Shale	
Cozzette Sandstone	Castlegate Sandstone	
Corcoran Sandstone	Morapos Sandstone	
Sego Sandstone	Meeker Sandstone	
Anchor Tongue of Mancos Shale	Mancos B	Possibly equivalent
Lower Sego Sandstone	Emery Sandstone	

There seems to be some agreement among authors to include all but the Morapos, Meeker, Mancos 8 and Emery Sandstones in the Mesaverde Group. This philosophy is followed in this report. Literature concerning the Castlegate and Sego Sandstones is available, and descriptions are therefore included to provide some understanding of these regressive sandstones.

The Neslen, Farrer, Tusher and Blackhawk Formations are restricted to Utah and are not considered further. The literature is not clear on how the southern names relate to the northern nomenclature. Therefore, a description of each is given realizing that some redundancy exists.

Castlegate Sandstone

The Castlegate Sandstone was deposited in environments varying from continental inland at the type locality near Castlegate, Utah, through lagoonal, littoral and epineritic going east into Colorado. The unit loses its identity in an infraneric environment along an arbitrary line that runs from a point near the Utah-Colorado border, N40 to N45E, to the White River Dome west of Meeker, Colorado (Hale, 1979, p. 60).

Along the Book Cliffs the Castlegate Sandstone ranges from massive conglomeritic sandstone near Castlegate to finegrained siltstone at the east boundry of Utah and passes entirely into shaly beds in western Colorado (Fisher, Erdmann and Reeside, 1960, p. 14).

Sego Sandstone

Thickness of the Sego Sandstone varies from 175 ft in Utah to termination near Palisade, Colorado. In Colorado, the Sego Sandstone is subdivided into the lower Sandstone Member, the Anchor Mine Tongue of Mancos Shale, and the upper Sandstone Member (Fisher, Erdmann, and Reeside, 1960, p. 1516).

The upper part of the lower Sandstone Member consists of two massive medium-grained buff to yellow-brown sandstone beds with an intervening thinner-bedded sandstone. The lower part consists of sandstone, sandy shale and clay shale in beds up to 2-1/2 ft thick. They are lenticular and at places contain mud pellets and fragments and carbonaceous matter (Fisher, Erdmann, Reeside, 1960, p. 1516).

The Anchor Mine Tongue of Mancos Shale resembles the Mancos Shale as previously described (Fisher, Erdmann, and Reeside, 1960, p. 1516).

The upper Sandstone Member of the Sego Sandstone appears as a massive gray cliff, some what lighter in color than the Mancos Shale below. It consists of a great number of thin or platy beds of sandstone, usually laminated and in many places crossbedded (Fisher, Erdmann, and Reeside, 1960, p. 15-16).

In general, the sandstone of the Sego is medium grained, sucrosic, soft and friable. It is largely composed of quartz, but locally contains an abundance of ferromagnesian minerals. Throughout most of its extent, the upper 10 or 15 ft is lighter than the underlying buff and brown strata (Fisher, Erdmann, and Reeside, 1960, p. 1516).

Gill and Hail (1975) indicate a nomenclature change in the northwest Piceance Basin at or just past their Pinyon Ridge section. Here the Sego Sandstone becomes part of what is referred to as the Iles Formation. In the southern Piceance Basin, Gill and Hail (1975) indicate that the lower Sego Sandstone terminates near the Corcoran Mine north of Grand Junction, Colorado. The upper Sandstone Member terminates approximately 8-1/2 miles southeast of the Grasso mine northwest of Palisade, Colorado.

Iles Formation

In the Yampa area the Iles Formation is 1,350 to 1,580 ft thick. It is a variable succession of coal-bearing sandstones and shales. The formation inter-tongues with the underlying Mancos Shale and is conformably overlain by the Williams Fork Formation.

The basal member of the Iles Formation, the Tow Creek Sandstone, is a prominent ledge former in the Yampa district West of Phippsburg this sandstone is light brown to light gray, medium grained, crossbedded and massive.

A 600 ft succession of rock overlying the Tow Creek Sandstone consists of a variable sequence of light-gray to pale-brown, mediumgrained, ledge-forming sandstones with interbedded dark-gray to brown carbonaceous shale and coal.

A 98 ft sequence of sandstones overlie the 600 ft interval described. The sandstones are light gray to pale brown, fine grained, crossbedded in part and extremely massive.

Overlying this 98-ft sandstone is a 350- to 425-ft succession of light-brownish-gray sandstones, dark- maroon to brown siltstones, carbonaceous dark-gray-shales and minor coal seams.

The Iles Formation is capped by the Trout Creek Sandstone, a light-gray to white, fine-to medium-grained, extremely massive ledgeformer, 132 ft thick.

Williams Fork Formation

Thickness of the Williams Fork Formation ranges from 1,100 ft near Mount Harris to over 5,000 ft near Meeker (Hancock and Eby, 1930, p. 203). It conformably lies on the underlying Trout Creek Sandstone.

The lower portion of the Williams Fork Formation consists of light-yellowish-gray to dark-gray, fine to medium-grained, thin-bedded, carbonaceous sandstones with interbedded light-brown to light-gray, crossbedded siltstone, gray shales containing limonite nodules and coal beds. This succession is overlain by thin sandstone beds, shale and thick coal beds of the middle group.

Overlying the middle coal group is the Twentymile Sandstone Member, 100 to 200 ft thick, of light-gray to white fine-grained sandstone.

The Twentymile Sandstone Member is overlain by an upper section of rock 850 ft thick east of Craig and 200 ft thick in the vicinity of Mount Harris (Bass, Eby, and Campbell, 1955, p. 158-159). It consists of sandstone, sandy dark-gray shale and a few coal beds belonging to the upper coal group.

Mount Garfield Formation

Fisher, Erdmann and Reeside (1960) described the Mount Garfield Formation in the Book Cliffs of Utah and Colorado. The following is a summary of their description.

The Mount Garfield Formation ranges in thickness from 970 to 1,070 ft and contains most of the coal beds of Colorado. The lower part, ranging in thickness from 305 to 666 ft constitutes the "coal measures." The upper part, ranging from 405 to 665 ft thick, constitutes the "barren measures." In the lower part a prominent sandstone bed is referred to as the Rollins Sandstone Member. The Mount Garfield Formation is conformable with the Sego Sandstone below and the Hunter Canyon Formation above.

The lower part, or "coal measures," consists of sandstones, shale, sandy shale, carbonaceous shale and coal beds. The sandstone beds are of several types — white, massive, apparently littoral beds; irregular, but massive buff sandstone beds of fluviatile origin with partings of shale and shaly sandstone; and thin irregular sandstone layers intercalated in beds of gray shale.

The Rollins Sandstone Member is similar to the Sego Sandstone. The weathered surface is light yellow, gray and brown; the fresh surface, grayish white to white. It is crossbedded, coarse grained and sucrosic.

The upper part of the "barren measures" contains very little coal. There is somewhat less sandstone, but the beds are slightly more arkosic and more massive. In color, structure and grain size the sandstones are similar to those of the "coal measures." The shaley beds in the "barren measures" are like those below, but locally are much thicker.

Hunter Canyon Formation

The Hunter Canyon Formation consists of massive brown-buff and gray sandstone and soft-gray shale beds and ranges in thickness from 375 to 1,400 ft. The sandstone beds are more numerous, coarser, grayer and more massive than those of the Mount Garfield by the virtual absence of carbonaceous shale and by the presence of some greenish shale beds (Fisher, Erdmann, and Reeside, 1960, p. 20).

The sandstone beds are medium to coarse grained and in beds 10 to 40 ft thick, but locally aggregating as much as 300 ft. The bedding is generally regular, but even thick beds may finger into shale abruptly. Crossbedding is common and channeling fairly common. Gray and greenish-gray shale and sandy shale are abundant (Fisher, Erdmann, and Reeside, 1960, p. 20).

Gill and Hail (1975) indicate a nomenclature change approximately 5 miles southeast of Watson Creek. Although an arbitrary boundary, the Hunter Canyon and Mount Garfield Formations here become the Mesaverde Formation. Where this nomenclature change occurs to the north and how the Iles and Williams Fork Formations are related is unclear.

Lion Canyon Sandstone

The Lion Canyon Sandstone, Lewis Shale, Fox Hills Formation and Lance Formation occur extensively in Sand Wash Basin and extend into the northern portion of the Piceance Basin. All merge to the south with the Upper Mesaverde or Williams Fork Formation.

The Lion Canyon Sandstone is mostly a barrier beach and shale sequence that laterally occurs between the upper Mesaverde or Williams Fork paludal deposits and the Lewis marine shale deposits. It is a light gray to white to brown, mostly fine to coarsegrained sandstone and gray shale with some thin interbeds of coal. The Lion Canyon Sandstone is conformable with the underlying Williams Fork Formation and the overlying Lewis Shale (Irwin, 1977).

Brenneman (1977) indicates merging of the Lion Canyon Sandstone with the Williams Fork Formation in northern Rio Blanco County.

Lewis Shale

The Lewis Shale is a gray marine shale with some interbedded gray, finegrained sandstone. Upper and lower contacts are conformable. The Lewis extends into northern Rio Blanco County where it inter-tongues and merges with the Williams Fork Formation (Irwin, 1977).

Fox Hills Sandstone

The Fox Hills Formation is interbedded gray, very fine to finegrained sandstone and calcareous gray shales. Upper and lower contacts are conformable (Irwin, 1977). The Fox Hills merges with the Lance Formation in central Rio Blanco County (Brenneman, 1977).

Lance Formation

The Lance Formation is interbedded gray claystones, shales, siltstones and finegrained sandstones with occasional thin coals. The upper contact is unconformable and the lower conformable. To the south and west beyond the zero line of the Lewis Shale, the Lance inter-tongues and merges with the Mesaverde Formation.

Ohio Creek Conglomerate

The Cretaceous-Tertiary boundary is marked by a major regional disconformity. A kaolinized zone occurs just below the disconformity, one above the disconformity and one below. The overlying unit is as much as 65 ft thick and contains abundant rounded pebble to cobble size clasts. The lower unit is as much as 328 ft thick and consists mostly of a sandstone with a few scattered lenses of conglomerate (Johnson and May, 1978).

The name Ohio Creek Formation has been assigned to each of these units by previous workers. Gaskill (1963) called the lower unit Ohio Creek Formation and put the upper one into the Wasatch Formation. Donnel (1961) called the upper unit Ohio Creek Formation and put the

lower one in the Mesaverde. Both workers thought that the age of the Ohio Creek Formation was Paleocene but had no paleontological evidence from the type section. Johnson (1980) has redefined the Ohio Creek as a member of the Hunter Canyon or Mesaverde Formation of Upper Cretaceous age.

2.14 TERTIARY SYSTEM

Donnel (1961) did a study entitled "Tertiary Geology and Oil Shale Resources of the Piceance Creek Basin Between the Colorado and White Rivers, Northwestern Colorado." In this report, Donnel described the Tertiary formations of concern to the present investigation. The descriptions that follow are modified versions of those given by Donnel.

PALEOCENE SERIES

Fort Union Formation

Donnel (1961) described a sequence of sandstone and shale above the Ohio Creek Conglomerate which he left unnamed. He did feel that the sequence is probably correlative with a part of the Fort Union Formation. The unit consists of massive brown and gray, poorly consolidated feldspathic sandstone beds, gray and brown clay and shale beds, and a few thin coal beds. The unit ranges in thickness from a little more than 500 ft along the Grand Hogback, about 13 miles north of Rifle to 0 ft in the southwestern part of the study area.

The Fort Union rests conformably, and in places gradationally, upon the Ohio Creek Conglomerate in the eastern and southern parts of the area. On the west, the contact between this unit and the Mesaverde Group is obscure. Due to a gradational contact with the overlying Wasatch Formation, the upper boundary has not been determined.

EOCENE SERIES

Wasatch Formation

The Wasatch Formation ranges in thickness from 5,500 ft in General Petroleum well 84-I 5G, Sec. 15, T2S, R96W to 375 ft in the northwestern part of the basin on Big Spring Creek in Sec. 28, T1N, R100W.

The Wasatch Formation in the area consists predominately of brightly-colored clay and shale. Shades of red are the most typical color, but purple, gray, green, lavender and yellow are common. Lenticular sandstone is prevalent and locally it is a common component. Local minor lithologic components are conglomerate, pebbly sandstone, limestone, coal and black carbonaceous shale.

The base of the Wasatch Formation is indefinite, for there is a gradual transition downward into the somber-colored beds of Paleocene age. The upper contact is generally placed where the irregularly-bedded and brightly colored sedimentary rocks give way to more regularly bedded non-red rocks, generally sandstone, of the Green River Formation. The color change is the main criterion for determining the boundary. In many places this contact is transitional.

Green River and Uinta Formations

Sedimentary rocks of the Uinta and Green River Formations are the surface rocks over most of the area studied by Donnel (1961). Due to erosion, the total original thickness of the Uinta and Green River Formations is not known. A maximum of more than 3,000 ft is present in the northeastern part of the area.

Green River Formation

The Green River Formation is composed predominately of dark shale and magnesium marlstone, some of which yields oil on distillation. These beds weather to shades of light gray, light blue gray, or light brown with a definite whitish aspect. Sandstone, siltstone, limestone and oolite are other lithologic components which are prominent in parts of the formation. The formation is characterized by remarkably regular thin-bedding and lateral persistence of some thin units.

In the southwestern portion of the Piceance Basin, the formation is divisible into four lithologic units. These units were named respectively the Douglas Creek, Garden Gulch, Parachute Creek and Evacuation Creek Members by Bradley (1931, p. 9). The Evacuation Creek Member has since been assigned to the Uinta Formation by Cashion and Donnel (1974).

Douglas Creek Member

The Douglas Creek Member ranges in thickness from 22 ft in the General Petroleum well 51-28 in Sec. 28, T1S, R97W, to a maximum of nearly 800 ft in the type section at the head of Trail Creek near the center of T4S, R101W.

The member consists primarily of crossbedded and ripple-marked sandstone, algal and ostracodal limestone, and oolitic sandstone and limestone with minor amounts of gray shale. It is brown to buff in color.

The Douglas Creek Member conformably overlies the brightly-colored Wasatch Formation. At many places the contact is transitional. The Douglas Creek Member is conformably overlain by the Garden Gulch Member.

Garden Gulch Member

The Garden Gulch Member ranges in thickness from 100 ft along Lake Creek to 1,900 ft in wells in the Piceance Creek gas field.

The Garden Gulch Member is similar to the overlying Parachute Creek Member with the principle difference being the lack of oil and carbonate. It is characterized by much papery to flaky shale. Marlstone, generally barren of oil, is a prominent lithologic component of the member. Thin beds of sandstone, oil shale breccia, and ostracodal, oolitic and algal limestone are locally present.

Anvil Points Member

The Anvil Points Member ranges from 1,530 ft at the type locality to a maximum thickness of 1,870 ft in the upper Piceance Creek. It is the lateral equivalent of the Douglas Creek and Garden Gulch Members and the lower part of the Parachute Creek Member of the southwestern Piceance Basin. The member is restricted to the eastern part of the Piceance Basin.

The Anvil Points Member is an extremely heterogeneous unit. At the type locality it contains approximately 30 percent gray shale, 25 percent gray and interbedded thin-bedded brown and gray sandstone, 20 percent massive brown and gray sandstone beds and slightly less than 10 percent light-brown marlstone containing little or no oil.

To the north the upper part of the Anvil Points Member inter-fingers with and is replaced by oil-shale beds in the lower part of the Parachute Creek Member. The base of the Anvil Points Member interfingers with the Wasatch Formation to the east.

Parachute Creek Member

The Parachute Creek Member ranges in thickness from 500 ft near the headwaters of Little Spring Creek to 1,700 ft in the General Petroleum well 5-31-G, Sec. 31, T1S, R96W. It is recognized throughout the area. The member is almost entirely shale and marlstone, most of which will yield oil when distilled.

Bradley (1931, p. 11 and p. 7) subdivided the Parachute Creek Member at the type locality into a lower and upper oil-shale group, separated by a thin sequence of oil-poor beds. Duncan and Denson (1949) further subdivided Bradley's upper oil-shale group into the upper and middle oil-shale zones, separated by a thin sequence of marlstone containing little or no oil. Donnel (1961) combined the middle and lower zones.

In the northern part of the Piceance Basin, the combined lower and middle zones are 1,000 ft thick. In the extreme northwestern part of the study area, northwest of Little Spring Creek, the combined lower and middle zones pinch out entirely between the Garden Gulch Member and the upper oil shale zone.

The upper oil shale zone has a maximum known subsurface thickness of about 620 ft in the General Petroleum well 84-15-G, Sec. 15, T2S, R96W; on the outcrop its thickness ranges from about 300 ft in the extreme northwestern part of the area to about 680 ft near Low Ridge.

Certain oil shale units within the upper oil-shale zone have been given separate designations because of their special importance. Of particular interest is the basal part of the upper oil-shale zone which is almost entirely rich oil shale. The unit is called the Mahogany Ledge at the outcrop and the Mahogany Zone in the subsurface. Within the Mahogany Ledge or zone is a persistent thin unit of exceedingly rich oil shale referred to as the Mahogany Bed.

Uinta Formation

The Uinta Formation, previously referred to as the Evacuation Creek Member of the Green River Formation forms the surface rock over most of the area of Donnel's report. Because this formation is presently an erosional surface in the study area, the maximum thickness cannot be determined. However, a thickness of 1,250 ft in the General Petroleum well 45X-29-G, Sec. 29, T2S,R95W, is the greatest recorded thickness in the area.

The formation is composed of barren marlstone, shale, siltstone and sandstone. Sandstone becomes increasingly prominent toward the top of the member. Some beds of oil shale are present near the base in parts of the area. It is buff to light brown in color.

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